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RESEARCH ARTICLE

The performance of nature reserves in capturing the biological diversity on Hainan Island, China

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Abstract
Purpose The performance of nature reserves depends on the degree to which they represent a region's full biodiversity. Here, we conducted a study on Hainan Island, China, to assess how well Hainan's biodiversity features were captured by existing nature reserves. We also explored the driving forces behind the current protection pattern so as to provide guidelines for improving the island's conservation system.
Methods We integrated the information on nature reserves, ecological variables, and human activities into a spatial database, then assessed the performance of nature reserves in representing natural variation, vegetation types, and species, and examined the impacts of human activities and land ownership on the current protection pattern.
Results About 8.4% of Hainan Island was protected by nature reserves; the coverage was geographically biased toward its central mountainous areas with higher elevation, rugged terrain, and fertile soils. We found that 60% of the environmental units and 39.4% of the natural vegetation types had more than 10% of their area protected, respectively. Lowlands tended to have higher animal species richness, and the protection for endangered species was less efficient. Nature reserve coverage was negatively correlated with amount of converted habitats, human population density, and road density, and 82.4% of the total reserved area was allocated on state-owned land.
Conclusions Nature reserve coverage was not enough to capture lowlands biodiversity features. The current protection pattern was significantly driven by several major conservation targets, human development, planning methods, and land ownership. To improve its conservation system, Hainan should enhance protection in the north and northeast plains and coastal regions, implement systematic planning approaches to define clear visions for guiding future conservation actions, and develop flexible management and funding mechanisms toward sustainable use of natural resources.

Keywords Biodiversity conservation · Environmental units · Hainan Island · Land ownership · Nature reserve · Systematic conservation planning · Terrestrial vertebrate species · Vegetation types

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1 Background, aim, and scope

Protected areas (PAs) are internationally recognized as cornerstones of biodiversity protection (Andelman and Willig 2003; Coad et al. 2009), and ideally, a sufficient sample of each of a region's ecosystems should be protected to guarantee the long-term persistence of the widest possible variety of life (Groves 2003). The Convention on Biological Diversity (CBD) has established a target for the protection of at least 10% of each of the world's ecological regions by 2010 (CBD 2004). However, numerous studies have revealed that existing PAs do not sample biodiversity adequately (Andelman and Willig 2003; Brooks et al. 2004; Rodrigues et al. 2004; Coad et al. 2009; Schmitt et al. 2009). Some biodiversity elements are absent from protection, while others are overrepresented (Pressey 1994; Rouget et al. 2003). Most PAs have been set up in an ad hoc manner (Pressey 1994). Their distribution is biased toward those areas that are least valuable for commercial uses or that are remote, unproductive, easy to set aside, and usually with the least need for protection (Knight 1999; Margules and Pressey 2000; Scott et al. 2001; Margules et al. 2002). Systematic measures of the distribution pattern of existing PAs relative to biodiversity should be applied so as to provide guidelines for the future design and improvement of PA networks.

Hainan Island is one of the most biodiversity significant parts in China (Chen 1993; Zhang and Ma 2008) and is also located within the Indo-Burma global biodiversity hotspot (Myers et al. 2000). The island is characterized by tropical ecosystems which, however similar with other tropical areas, have experienced serious damage (Jiang et al. 1998; Wang et al. 2005). Habitat loss caused by competing land uses from development is the major threat to biodiversity.

Hainan's global biodiversity significance and the intense conflicts between conservation and development have put it in the limelight. The island instituted a logging ban on natural forest in 1994, 4 years earlier than a similar policy on the mainland. Hainan provincial government is planning to allocate 9% of its land to nature reserves (NRs) by 2015; over 8% was already under protection at the end of 2009. Although 9% may be an ambitious conservation goal, this figure itself will not ensure the effective conservation of the island's biodiversity. Without systematic conservation planning, we might still fail to protect the places that contribute most to the island's representative biodiversity though the overall NR coverage is increased. The allocation of existing NRs has been mainly driven by opportunity, and so far, little is known about the contribution that NRs are actually to for the island's conservation.

Our aim here is to examine how well Hainan's biodiversity features are captured by the existing NR system and explore the possible driving forces for the current protection pattern so as to provide guidelines for improving Hainan's conservation system. We therefore compiled a spatial database with datasets on NRs, environmental units (i.e., combinations of the three abiotic variables of elevation, terrain ruggedness, and soil fertility), vegetation types, terrestrial vertebrate species, and human impacts (including converted habitats, human population density, and road density). Then, we assessed the performance of NRs in capturing the island's biodiversity features. After that, we examined how the geographic distribution of NRs covaries with human impacts, and discussed the possible driving forces for the current configuration of NRs, and suggested a strategic plan for improving the effectiveness of the island's NR system.

2 Materials and methods

2.1 Study area

With an area of about 34,000 km^2, Hainan is the second largest island in China. It is located in the tropical monsoon climate zone (Fig. 1). The island, amounting to only 0.35%

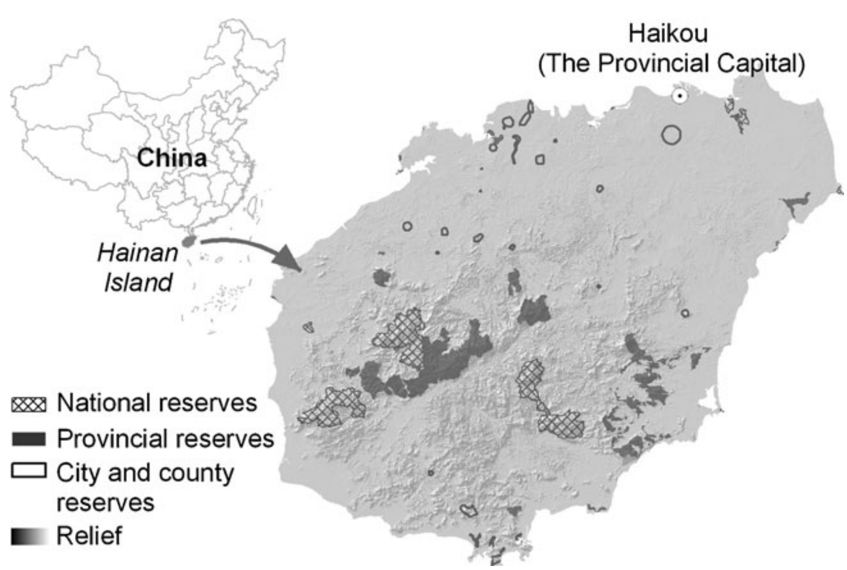

Fig. 1 Hainan Island and the distribution of nature reserves. *Shaded relief* is used to illustrate terrain roughness

of China's land area, contains more than 4,000 higher plant species (about 7% of the country's total number; Chen 1993; Wang et al. 2005) with 505 species endemic to the island (Xing et al. 1995). Hainan has 575 terrestrial vertebrate species, including 76 mammals, 355 birds, 105 reptiles, and 39 amphibians. Of the 575 terrestrial vertebrate species, 90 are on "China's National Protected Wildlife" list (CNPW; Shi 2001). Tropical forests on the island have been seriously shrunk in extent and degraded in function, and the average coverage of natural tropical forest was estimated to be less than 20% as of 1998 (Lin and Zhang 2001). The mountainous area located in the island's central region remains relatively natural with higher forest coverage, and most NRs are concentrated there (Fig. 1).

2.2 Spatial distribution data of NRs

The NR data were based on the official NR list issued by the Department of Land Environment and Resources of Hainan Province in 2005, together with additional information on NRs established between 2005 and 2009. NRs in China are dedicated mainly to nature conservation and are administered by four different administrative levels of government (national, provincial, city, and county). As this analysis was focused on Hainan's terrestrial ecosystems, we excluded all 11 marine NRs. Thus, a total of 59 NRs were involved in our analysis, and they belong to the categories of forest ecosystems, wild animals, wild plants, inland wetlands, geological heritage, and costal ecosystems, which cover almost the entire extent of PA categories listed by International Union for Conservation of Nature (IUCN 1994; Jiang et al. 2004). Among them, 7 are national NRs, 18 provincial NRs, and 34 city and county NRs (Fig. 1).

The polygon boundaries of the 59 NRs were created using several approaches depending on the information available: (1) 28 boundaries were defined using coordinates measured in the field via the Global Positioning System; (2) 23 were defined from the NRs' own master plans at a scale of 1:50,000; (3) 8 were defined using point data buffered by their reported area to provide an estimate for their coverage (Bubb et al. 2009).

2.3 Data on elevation zones, terrain ruggedness, and soil fertility

A digital elevation model (DEM) with 20 m×20 m pixels was created by interpolating the vector contour data (with 10-m intervals) which were digitized from the 1:50,000 topographic maps. We derived seven elevation zones from the DEM according to previous studies on geomorphology (Yuan et al. 2006; Li et al. 2008). The classification schemes were <5, 5–100, 100–250, 250–500, 500–750, 750–1,000, and >1,000 m.

The terrain ruggedness index (TRI) was obtained by calculating the average difference in elevation between a center cell and its eight neighbor cells (Riley et al. 1999). Then, we broke the TRI values into five classes with the Standard Deviation Classification Scheme. The five classes corresponded to the terrain categories of level (<85 m), slight rugged (85–204 m), moderate rugged (204–323 m), severe rugged (323–442 m), and extreme rugged (>442 m).

We created a soil fertility map based on eight factors (i.e., bulk density, soil texture, plant available water, depth to rock bed, and total nitrogen, phosphorus, kalium, and organic matter) that are commonly used in assessing soil quality (Sun et al. 1995; Zhang et al. 2001; Lv and Li 2006). All these data came from 1:200,000 soil maps (Gong et al. 2004). Initially, each of these factors was stratified into three categories based on their effects on soil fertility as indicated by previous studies (Lv and Li 2006; Yu 2008), and ranked as 1 (low), 2 (intermediate), and 3 (high). They were then spatially overlaid and combined to produce a single data layer by summing the rankings of all the factors. The values were then divided into three classes by using the Quantile Classification Scheme with the ranks 1–3 as mentioned above. The final map represented the region's pattern of current soil fertility (CSF; Fig. 2a).

To be comparable with previous studies in terms of the NR protection pattern on soil fertility, we created another soil fertility map following Pressey et al. (1996). We defined three soil fertility classes based on rock matrix types (hereafter, soil fertility based on rock matrix types, SFRM) with data derived from 1:200,000 geology map (Guangdong Provincial Geologic Surveying Bureau 1965) and ranked them with 1–3 as mentioned above (Fig. 2b). The classes were determined by using a classification system based on Xie (2004), which evaluated the potential influence of rock types on soil fertility according to rock weathering speed, texture, and mineral nutrients.

2.4 Definition of environmental units

Abiotic variables have been shown to influence the distribution of biological features at multiple scales, and ideally, NRs should be set up across the region's natural variation in order to preserve the full range of ecological and genetic diversity in species and maintain their potential to respond to varying conditions (Burnett et al. 1998; Nichols et al. 1998; Scott et al. 2001; Sappington et al. 2007). They also have obvious importance in determining the potential for various land uses, and the explanation of patterns of protection and other land uses relies mostly on analyses of physical characteristics (Pressey et al. 1996). To

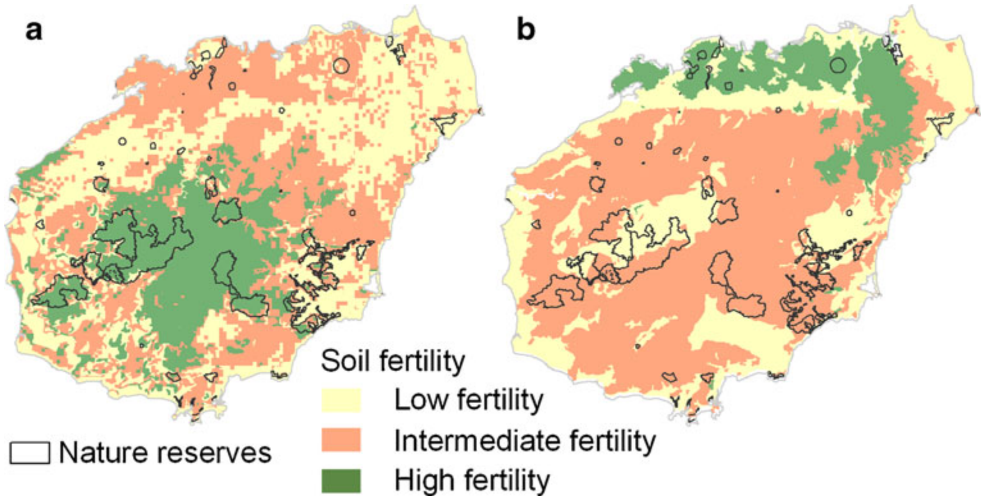

Fig. 2 Maps of soil fertility overlaid with nature reserves. **a** Current soil fertility (CSF). **b** Soil fertility created based on rock matrix types (SFRM)

examine the protection pattern of natural variations, we created 90 classes of environmental units by uniquely combining the elevation zones, TRI classes, and CSF classes. In contrast to the environmental domains derived by more complex multivariate analyses of abiotic data (Groves 2003), the environmental units on the basis of simple combinations of variables make the association of each of the abiotic variables with NRs and other land uses transparent (Pressey et al. 1996).

2.5 Vegetation types and species

We examined NRs' representation for biotic elements by using vegetation types as a surrogate. The vegetation data were based on the Hainan Island Vegetation Map (South China Institute of Botany 1985), which is the only vegetation data available currently. Thus, 42 vegetation types, including 9 cultural types, were mapped, and we analyzed NRs' coverage for the 33 natural vegetation types.

We primarily focused on terrestrial vertebrate species. The corresponding author of this paper had led a comprehensive survey on terrestrial vertebrate species across the island during 1997–1998 (Jiang HS, unpublished data). In that survey, a total 752 surveying transects were completed on mammals, birds, amphibians, and reptiles. For the mammal survey, species in *Chiroptera* and *Muridae* were excluded because the survey of these two groups of species requires specific survey methods and additional equipment, and the project did not have enough budgets to cover expenses. Therefore, the survey recorded 29 mammal species which accounted for 74% of the known mammal species on Hainan except those in *Chiroptera* and *Muridae*. The survey recorded 247 birds, 32 amphibians, and 56 reptiles which accounted for 70%, 82%, and 53% of the known species in each group, respectively. For each observed species, additional information, including numbers, relative position in the surveying transects, habitat types, and human impacts, was also recorded. Survey priorities were given to the species listed in CNPW, and a total of 50 CNPW species were recorded in the survey with 12 for mammals, 35 for birds, 1 for reptiles, and 2 for amphibians, while Hainan's current CNPW full list has 90 species (13 for mammals, 67 for birds, 8 for reptiles, and 2 for amphibians). This survey remains the only systematic and comprehensive investigation of terrestrial vertebrate species on the island to date.

We identified the distribution of threatened species from the survey data by referring to the species listed in CNPW, Convention on International Trade in Endangered Species (CITES) appendices I and II (CITES 2009), IUCN Red List of Threatened Species (2009), and China Species Red List (Wang and Xie 2004).

2.6 Data on land uses, human population density, roads, and land ownership

We created a map of human land uses by visually interpreting SPOT5 satellite imageries which were acquired between 2005 and 2007. We considered the following land use types as converted habitats: cropland (irrigated and nonirrigated), rural settlements, urban areas, commercial land, and industrial land. Raster data on human population density with a 1-km resolution came from the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (Yang and Ma 2009). The road network was derived from 1:50,000 topographic maps. We derived forest land ownership from the forests data developed by the ecological forests and natural forests conservation projects implemented by Hainan Provincial Forest Department. Ownership data for other kinds of land uses are not publicly available. Since most NRs are allocated on forest lands, our analysis on forests ownership should be representative for understanding how land ownership can affect the NR coverage pattern. The forest land ownership is classified as state-owned, collectivity owned, and private.

2.7 Data analysis

We examined the protection pattern of NRs in relation to biodiversity features through a series of spatial overlays. To explore the impacts that human activities have on the spatial pattern of the current NR system, we calculated percentages of converted habitats (PCH), mean human population density (MHPD), and mean road density (MRD) within each environmental unit. We used arbitrary weights to consider the impacts of different levels of roads, and MRD was calculated as weighted average road length per unit area within each environmental unit. We then examined the pairwise Spearman's rank correlations between NR coverage and PCH, MHPD, and MRD. Spatial analyses were done with ArcGIS 9.3 developed by the Environmental Systems Research Institute.

3 Results

3.1 General pattern of NR coverage

The total area of NRs on Hainan Island was 2849.6 km^2 (about 8.4% of Hainan's land), with 32.7% as national NRs, 60.2% as provincial NRs, and 7.1% as city and county NRs. The NR coverage was geographically biased toward the central mountainous region which included more than 75% of the total NR area (Fig. 1). The distribution of NRs was also skewed in terms of size (from 0.15 to 507 km^2), with 63% of the NRs <20 km^2 and 44% <10 km^2. The five largest NRs (i.e., Yinggeling NR, Bawangling NR, Jianfengling NR, Diaoluoshan NR, and Wuzhishan NR), all for protecting tropical forest ecosystems, accounted about 56% of the island's total NR area. Although more numbers of NRs were established to protect mangrove forests, birds, wetlands, and geology relic in north and northeast plains and coastal regions, the NR coverage was very low, and NRs were small and isolated because natural habitats have been highly developed and seriously fragmented (Fig. 1). Most NRs on the island were established between 1981 and 1992, with only eight established before 1980 and nine established after 1992.

3.2 NR coverage of environmental units

We found that 50.8% of Hainan's land was below 100 m in elevation and that 89.6% was below 500 m in elevation. About 78.9% of the island was level and slight rugged, 12.9% was moderate rugged, and 8.2% was either severe or extremely rugged. Twenty-three percent of the island belonged to the CSF class 3, while the coverage for class 1 and class 2 was 37.7% and 39.4%, respectively (Table 1). However, in terms of the distribution of total NR area, 48.7% was allocated at places above 500 m in elevation, and 66.7% was at mid-to-high rugged terrain with TRI classes 3–5, and 62.0% was in the highest CSF class 3 (Table 1). Altogether, 77% of the total NR area occurred at these places, although they only accounted for 31% of the island.

Our study showed that as elevation, TRI or CSF increasing percentage of NR coverage went up. Higher value classes of these three variables had higher protection rate, e.g., both TRI class 4 and 5 had more than 30% protected, and 22.5% of CSF class 3 and 28–78% for elevation zones 5–7 were in the NRs (Table 1).

The protection patterns of the different classes of environmental units were biased with some units totally

Table 1 Distribution of land and nature reserve area on Hainan Island among three soil fertility classes (class 1 for low fertility, class 2 for intermediate fertility, and class 3 for high fertility), five terrain ruggedness classes (class 1 for level, class 2 for slight rugged, class 3 for moderate rugged, class 4 for severe rugged, and class 5 for extreme rugged), and seven elevation zones (class 1 for <5 m, class 2 for 5–100 m, class 3 for 100–250 m, class 4 for 250–500 m, class 5 for 500–750 m, class 6 for 750–1,000 m, and class 7 for >1,000 m)

Environmental variable	Area %	Code of environmental variable classes						
		1	2	3	4	5	6	7
Soil fertility	% of the island	37.7%	39.4%	22.9%				
	% of the total nature reserve area	19.3%	18.7%	62.0%				
	% in nature reserve	4.3%	4.0%	22.5%				
Terrain ruggedness	% of the island	62.4%	16.5%	12.9%	6.0%	2.2%		
	% of the total nature reserve area	15.6%	17.7%	30.6%	23.0%	13.1%		
	% in nature reserve	2.1%	8.9%	19.7%	31.7%	51.3%		
Elevation	% of the island	5.0%	45.8%	24.7%	14.1%	6.4%	2.8%	1.2%
	% of the total nature reserve area	3.7%	7.5%	17.8%	22.3%	21.6%	16.8%	10.3
	% in nature reserve	6.2%	1.4%	6.0%	13.1%	28.3%	49.3%	78.1%

protected while others were absent from NRs. Of the 90 environmental units, 54 (60%) units, which covered about 3.1% of Hainan's land, concentrated at the central mountainous region, had more than 10% of their area protected (Fig. 3a). Among these 54 units, 48 met at least one of the three environmental conditions: (1) TRI class ≥4, (2) elevation ≥500 m, and (3) CSF class=3. The other six units were all located at the transitional areas between the mountainous region and the lowland area, i.e., from relatively natural lands to the highly converted habitats. Most environmental units at the lowland area were less than 5% protected (Fig. 3a).

3.3 NR coverage of vegetation types

The coverage of NRs for natural vegetation types was extremely biased toward forests in mountainous areas (Fig. 3b). Of the 33 natural vegetation types, 13 types (39.4%) had more than 10% of their area protected. Among the 13 vegetation types, 11 were forest types including tropical forest and mangrove. Although natural forests cover only about 20% of the island's area according to the vegetation data, they accounted for 60% of the total NR area. In contrast, most scrub and grassland communities were not represented adequately. Nine vegetation types, including two forest types (*Carallia brachiata–Pavetta arenosa* forest, and *Pinus latteri* forest), five scrub types (*Grewia biloba–Buchanania arborescens–Eulalia phaeothrix*, *Phoenix hanceana–Flacourtia indica–Opuntia stricta* var. *dillenii*, *Chimonobambusa pachystachys–Memccylon ligustrifolium*, *Lannea coromandelica–Chimonobambusa pachystachys*, *Rhodomyrtus tomentosa–Pavetta arenosa–Eupatorium odoratum*), and two grassland types (*Eulalia speciosa–Cymbopogon goeringii–Heteropogon contortus*, *Leptocarpus disjunctus–Xyris indica–Nepenthes mirabilis*), did not occur in any NR.

3.4 Patterns of species distribution and NR coverage

Based on the data derived from the survey during 1997–1998, 86% of mammal species, 98% of bird species, 97% of amphibian species, and 91% of reptile species had occurrences below 500 m in elevation. The species richness tended to decrease with increasing elevation (Fig. 4a). Our survey recorded 67 endangered species, including 17 mammals, 42 birds, 2 amphibians, and 6 reptiles. Of these endangered species, 15 mammal species, all bird species, all amphibian species, and 5 reptile species had occurrences below 500 m in elevation. The number of endangered bird species decreased clearly as elevation increased (Fig. 4b). Although the current NR system has maintained many endangered species, there were still large numbers of endangered species in each of these four taxa occurring in highly converted habitats which may be close to or very far from NRs (Fig. 5). Specifically, endangered bird species distributed across more wide spatial scales (Fig. 5b). Most endangered mammal species occurred at places within or surrounding NRs, while the NR coverage for endangered amphibian and reptile species was less efficient (Fig. 5a, c, and d).

3.5 The associations of NR coverage pattern with human impacts and land ownership

There are intensive human activities on the island's north and northeast plains and coastal regions, and the central mountainous region is less affected. NR coverage rate within the environmental units was significantly negatively correlated with PCH ($r=-0.660$, $p<0.001$), MHPD ($r=-0.607$, $p<0.001$), and MRD ($r=-0.568$, $p<0.001$; Fig. 6). About 82.4% of Hainan's total NR area was found allocated on state-owned forest land, only 0.8% was on collectivity owned forest land, and almost no private land occurred within NRs.

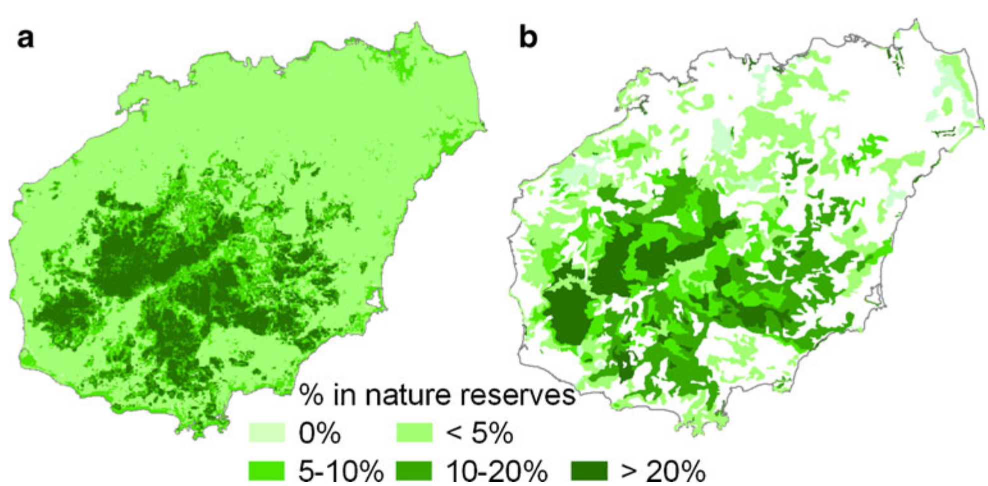

Fig. 3 Nature reserve coverage of **a** environmental units and **b** natural vegetation types

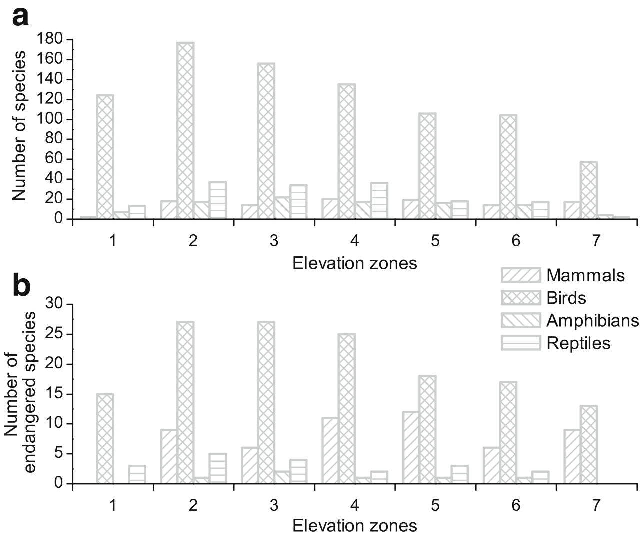

Fig. 4 Distribution of mammal species, bird species, amphibian species, and reptile species within elevation zones: **a** all species and **b** endangered species. Elevation zones: *1* (<5 m), *2* (5–100 m), *3* (100–250 m), *4* (250–500 m), *5* (500–750 m), *6* (750–1,000 m), and *7* (>1,000 m)

4 Discussion

4.1 General protection pattern

Our results showed that NR coverage on Hainan Island was highly concentrated at the central mountainous areas which are higher in elevation, rugged in terrain, and less affected by human activities (Fig. 1). Even though there were more numbers of NRs in north and northeast plains and coastal regions, the NR coverage there was low, and NRs were isolated from each other. We found that the majority of natural vegetation types were not adequately represented in NRs, with an exception that most forests ecosystems were well captured by NRs. The distribution of terrestrial vertebrate species was geographically extensive across both natural and converted habitats, and the current NR system was less efficient in capturing endangered species.

The small NR coverage at low-elevation-level areas indicated that the current NR system was inefficient to protect a representative sample of the island's biodiversity. Species with their optimal habitat in these areas might fail to be conserved and become extinct, and ecosystems distributed there may be subject to degradation. Our analyses support this argument. The natural vegetation types in Hainan's mountainous areas were well represented with up to 100% coverage, whereas most types at low-elevation-level areas were not protected adequately, and many did not even occur within any existing NRs. The majority numbers of animal species have occurred at areas below 500 m in elevation even where are experiencing intensive negative human impacts, and the species number decreased as elevation increased (Fig. 4a). Hunter and Yonzon (1993) also indicated that the richness of both plant and animal species decreases as altitude increases. We also found that almost all endangered species have occurrences at low-elevation areas (below 500 m in elevation) within highly converted habitats (Fig. 5).

Hainan's protection pattern in terms of elevation and terrain ruggedness agreed with studies conducted elsewhere (Pressey et al. 1996; Scott et al. 2001). However, the NR coverage pattern for soil fertility in our study seemed to be inconsistent with common knowledge (Pressey et al. 1996; Margules and Pressey 2000; Scott et al. 2001), which concluded that infertile areas tend to allocate more protected areas while we found the fertile areas on Hainan were more likely to be protected. We suspect that the discrepancy might result from that different types of factors were used to assess the soil fertility. Pressey et al. (1996) derived three soil fertility categories based on geological types of broad lithological classes. Scott et al. (2001) created a predicted soil productivity map by combining five factors generally thought to influence soil fertility: hydrologic soil grouping, depth to bedrock, rock fragment volume, available water capacity, and slope. These two studies assess only physical factors, and they provide good prediction over the original soil fertility from the aspect of physical processes of pedogenesis. However, we created our current soil fertility map by considering multiple physical and nutrient factors (i.e., total nitrogen, phosphorus, kalium, and organic matter). The nutrient factors were crucial for measuring actual soil fertility (Liu et al. 2006).

Our SFRM data, the soil fertility map developed based on the rock matrix types, support this assumption (Fig. 2b). The SFRM map showed very different pattern of soil fertility compared with the CSF map (Fig. 2a). For example, the most fertile area of SFRM in northern Hainan was at low or intermediate fertility in the CSF map, while the least fertile parts of SFRM in the central mountainous area were at the most fertile level in the CSF map (Fig. 2). The protection percentages were 8%, 10%, and 3% for the SFRM classes 1, 2, and 3, respectively. It indicated that the higher protection percentages tended to be in the infertile areas of SFRM map which agreed with previous studies.

There are two main reasons that might cause the different mapped patterns of soil fertility. First, soil formation is a result of complex processes involving the rock matrix, climate, living organisms, human activity, topography, and time lapse (Xie 2004; Lv and Li 2006). Different factors or methods selected to do the assessment might lead to different results. The physical factors, e.g., rock matrix types, are crucial for determining soil characteristics, especially at the initial stage of soil formation. While other factors, including climate, living organism, human activity, topography, etc., have significant influences on soil

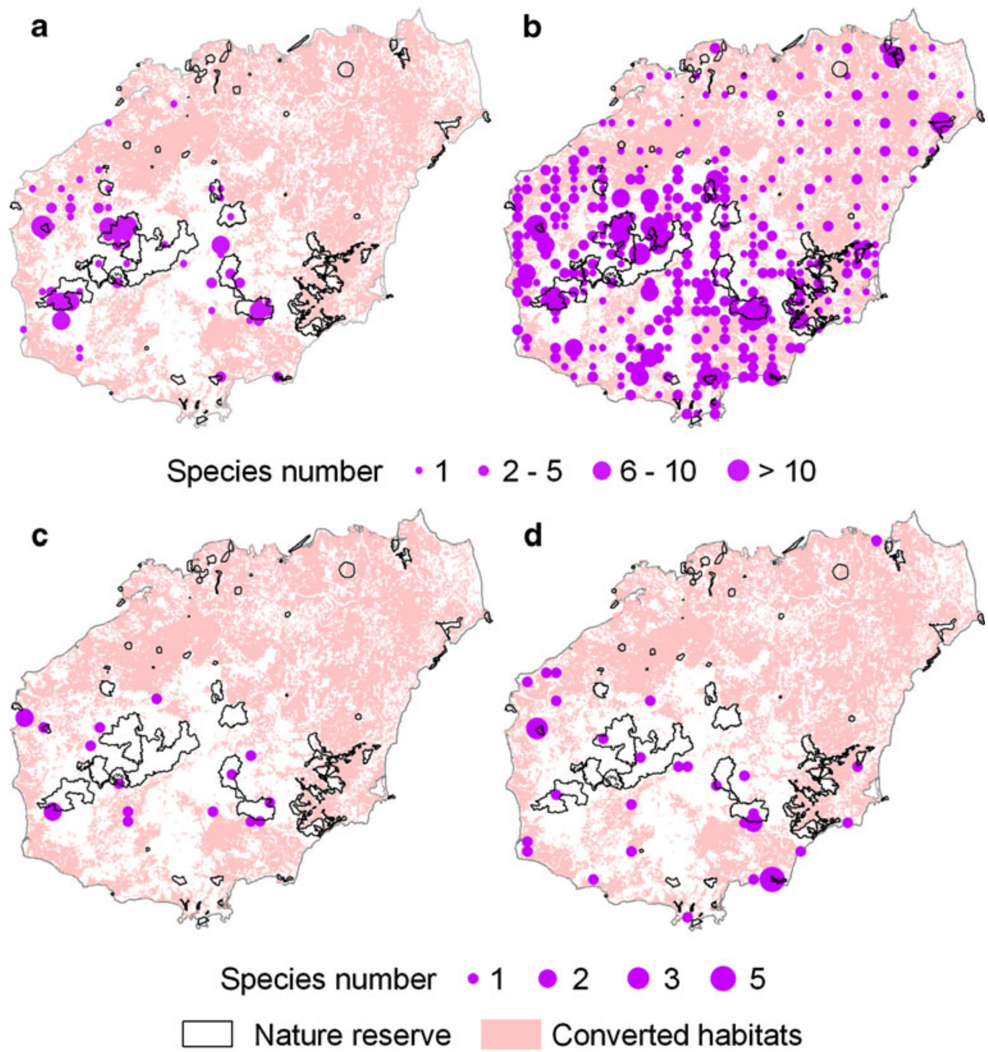

Fig. 5 Geographic distribution and richness of endangered species, including **a** endangered mammal species, **b** endangered bird species, **c** endangered amphibian species, and **d** endangered reptile species

formation at later stages that decrease the correlation between physical factors and soil fertility (Xie 2004; Lv and Li 2006). Thus, it might be problematic to assess soil fertility with only a few physical factors which usually influence fertility indirectly. Factors that could directly reflect the actual soil fertility, e.g., nutrient factors, should be used to do assessments.

Second, human activity may have significant impact on current patterns of soil fertility. The originally fertile soil according to the physical factors might have been worn out due to long-term human development, e.g., agriculture at low-elevation-level areas. Zhao et al. (2004) found that the soil fertility on Hainan decreases from the mountainous areas to the plains with the increase of human impact intensity, and the degradation pattern correlates with the land use types. The highest soil fertility is in forest, then shrub, grassland, and crop field. Another study conducted in southwest China's Chongqing Province shows the same pattern of soil fertility with respect to land use types (Sun et al. 2003). The poorer soil fertility might be a result of soil erosion caused by human activities (Zhao et al. 2004). Our CSF map showed that the best forested areas had the highest soil fertility (Fig. 2a). The results here indicate the irreplaceable role of natural ecosystems in providing important ecological services for sustaining human well-being such as soil retention on the island.

4.2 Possible driving forces for the current protection pattern

Establishment of NRs is a complex social process. We propose four driving forces for shaping Hainan's current protection pattern. First, the existing NR coverage pattern is apparently driven by several major conservation targets. Our results show that many large NRs were established in central mountainous areas to protect tropical forests, and many NRs in coastal regions to protect mangroves. Some other NRs were set up for protecting specific endangered species, such as Bawangling NR for protecting Hainan

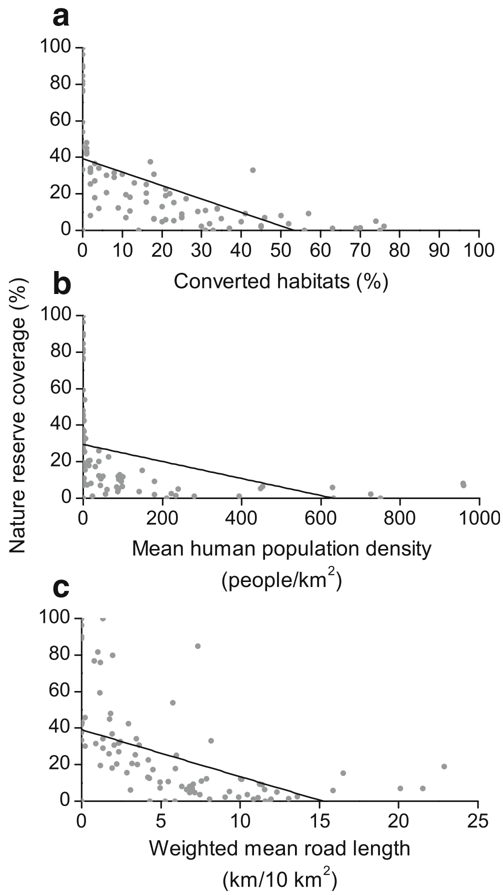

Fig. 6 Relationships between nature reserve coverage (%) and **a** converted habitats (%), **b** mean human population density (people/km^2) and **c** mean road density calculated as weighted mean road length per 10 km^2. The 90 environmental units were used as analysis unit

Gibbon (*Nomascus hainanus*), Datian NR, and Bangxi NR for protecting Hainan Eld's Deer (*Cervus eldi hainanus*), and Ganzhaling NR for protecting *Hopea exalata*, etc.

Second, economic development competes with NRs for land (Margules and Pressey 2000). Our analysis showed that the NR coverage within environmental units decreases as PCH, MHPD, and MRD increase (Fig. 6). Due to intensive human impacts and long-term development, most natural habitats at lowland and coastal areas have been converted to human use land or seriously degraded and fragmented which has greatly decreased the conservation value of these areas and made it difficult to establish more NRs. As a result, NRs tend to be concentrated on land that is remote and economically less valuable, such as the central mountainous areas on the island.

Third, Hainan's NR system has been built up within very short term (about three decades). Most NRs were set up opportunistically, and the whole system lacks design. A top-down process is implemented by government at different levels to establish NRs, and the site selection depends on expert opinions. Due to different interests, experts may see different places as important. Conservationists also have a strong tendency to protect wild areas which may further bias the protection pattern. Remote areas are also preferred for being cost-efficient.

Fourth, our analysis indicated that Hainan's NRs are mainly concentrated on state-owned forest land which covers 82.4% of the total NR area. Considering the lack of ownership data on other types of land uses, we suppose that state-owned land has contributed the most land for establishing NRs. State-owned land is preferred for allocating NRs because land ownership is clear and there are also fewer conflicts between conservation and community development. Many formerly state-owned forest farms have been transformed into NRs after the logging ban was issued, and it is also a benefit for conservation to build on the existing management system of forest farms. To date, 12 NRs has been established within Hainan's 11 state-owned forest farms.

4.3 Recommendations for improving Hainan's conservation

We have three recommendations for improving conservation on Hainan. First, north and northeast plains and coastal regions should be the focus for enhancing conservation in the future. Although their conservation value has been significantly decreased through long-term development and it is relatively difficult to do conservation, our analysis revealed that these places provide critical habitats for large numbers of common and endangered species. Meanwhile, to sustain long-term human welfare, certain proportions of natural ecosystems should be maintained in highly developed areas to provide ecosystem services, such as water purification, flood control and drought mitigation, and pollination for agriculture, etc. The proper configuration of natural ecosystems is particularly important for an isolated island like Hainan. Second, systematic conservation planning based on explicit targets and ecological goals is needed to identify priority conservation areas on the island. This will provide a clear vision for conservation decisions and ensure the representativeness of future PA network (Margules and Pressey 2000). For supporting the informed decision making, we suggest a comprehensive spatial database be established to integrate key information on environment, biodiversity, and socioeconomics. Such a database requires further field surveys to be conducted. Beyond the biological features, ecosystem services should be used as critical targets in conservation planning. Integrating of ecosystem services will make conservation broad-based, open new revenue streams, and begin to align economic forces with conservation (Chan et al. 2006).

Finally, in developed areas, where strict NRs may not always be an optimal option, flexible management and funding mechanisms should be established. Management for sustainable use using conservation principles as a primary goal should be encouraged. For instance, the State Forestry Administration of China (2010) has recently proposed a four-category framework for conserving forestry with different levels of strictness. Given government's limited resources, social funding should be encouraged to do conservation, such as allowing environmental organizations to purchase land for setting up reserves.

5 Conclusions

The NR coverage on Hainan Island was geographically concentrated at the central mountainous areas, while biodiversity features occurred at lowlands of north and northeast plains and coastal regions were not adequately captured in NRs. The current protection pattern was significantly driven by several major conservation targets, human development, planning methods, and land ownership. In order to preserve the full range of biodiversity features, we should strive to make Hainan's NR network be more representative of the region's natural variation. North and northeast plains and coastal regions are the focus for enhancing conservation in the future. Systematic planning approaches should be implemented to define clear visions for guiding future conservation actions. Flexible management and funding mechanisms toward sustainable use of natural resources should be developed, particularly at highly developed areas.

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